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Accommodating thermal features of commercial building systems to mitigate energy consumption in Florida due to global climate change

Aiyin Jiang*, Anna O'Meara

Department of Construction Management, University of North Florida, 1 UNF Drive, Jacksonville, FL 32224, USA

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ABSTRACT

Space cooling plays a major role in the commercial building energy consumption due to hot and humid climate in Florida. Although many studies have found that global warming would cause a decrease in heating requirements and an increase in cooling requirements, few of the studies propose mitigation of the cooling demands of the buildings. This study explores the mitigation measures, which include the thermal resistance features of wall and roof systems, visible and solar transmittance values of glazing material, thermal conductivity of windows, and set point temperatures of commercial buildings in Florida. The cooling demands are simulated by using the projected climate weather data in the periods between 2020 to 2100 in different cities. The cooling demands are reduced at various rates between 1% and 5% in all studied building types and in all climate zones by changing the thermal resistances of roofing systems from R-12/14/16 to R-19/21 and wall systems from R-13 to R-19/21. Increasing the wall thermal resistance features is more efficient in mitigating the cooling demands of buildings than increasing the thermal resistance features of roofing systems. In addition, the average values of visible transmittance and solar transmittance of glazing materials and thermal conductivity of windows for a high-rise apartment are suggested to be 0.3, 0.2 and 0.3 respectively.

1. Introduction

Global climate change has a significant impact on the energy demands of buildings. Various studies have projected that global warming would cause a decrease in heating requirements and an increase in cooling requirements [1,3,8,10–12,16,18,21–24,26,27,29]. In Europe, Frank [8] studied the impact of climate change on energy demands of office buildings in Switzerland. His calculations showed that the annual cooling energy demand for office buildings will increase by 223–1050%, while the heating energy demand will fall by 36–58%. Jentsch et al. [11,12] may be the first ones who analysed the impact of climate change on buildings of the United Kingdom; they applied the morphing algorithm to predict future weather. Olonscheck et al. [16] analysed future energy demand for heating and air conditioning of residential buildings in Germany until 2060. Results indicated that the future heating energy demands would decrease substantially and the cooling energy demands would remain low in the future unless the amount of air conditioners strongly increases. Asimakopoulos et al. [1] assessed building energy demands of three building types in Greece for the period 2010–2100. Results showed that the energy demands for heating the building sector in Greece could decrease by about 50%, while the respective energy demands for cooling could increase by as much as 248%. These effects were more evident in the southern part of the country.

In Australia, Wang et al. [23] investigated the potential impact of climate change on the heating and cooling energy requirements of residential houses in five regional climates varying from cold and dry to hot and humid. The total heating and cooling energy requirements of newly constructed 5 star houses is projected to vary significantly in the range of −26% to 101% by 2050 and −48% to 350% by 2100.

In Asia, the research conducted by Chan [3] indicates there will be a substantial increase in Hong Kong in cooling energy consumption under the impact of future climate change, ranging from 2.6% to 14.3% and from 3.7% to 24% for office buildings and residential flats, respectively. Wan [28] also studied the impact of climate change on office buildings and residential buildings in Hong Kong by using principal component analysis (PCA) method. The estimated increase in cooling energy use was in the range of 11.4%–55.7%. Zhu et al. [27] investigated the impact of climate change on the energy demands of four types of buildings in three major Chinese metropolises – Beijing, Shanghai, and Guangzhou – and predicted substantial growth of energy demands in the future. Radhi [17] focused on residential buildings in Saudi Arabia and concluded

* Corresponding author.
E-mail address: a.jiang@unf.edu (A. Jiang).

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that global warming could be likely to increase the energy used for cooling buildings by 23.5% if Al-Ain city would warm by 5.9 °C.

In North America, research conducted by Huang [10] indicated that the energy use for space cooling will increase in Los Angeles by as much as 31% in commercial buildings. Wang and Chen [22] studied the energy consumption for heating and cooling affected by climate change by simulating two types of residential buildings and seven types of commercial buildings in 15 typical cities across the United States. The change in peak heating demand of a single family house could be likely to decrease in the range of −25% to 0% while the change in peak cooling demand could be likely to increase in the range of 115% to 120%. The change in cooling energy of various building types located in 15 typical cities varied significantly from 30% to 280%.

The global climate change could cause cooling demands to increase at various rates while heating demands decrease or remain low. The future will offer greater challenges to the designers of sustainable buildings aiming to provide either entirely passive or low-energy comfort cooling [9]. New paradigms for building design and operation are necessary to protect the quality of life of those who inhabit them [19]. Wan [21] proposed to change the coefficient of performance (COP) of a chiller plant from the current minimum requirement of 4.7 to at least 5.5 and raise the summer set point temperature (SST) to 25.5 °C or higher to alleviate the impact of climate change on high energy demands in Hong Kong. Radhi [17] pointed out that in Saudi Arabia the thermal insulation and thermal mass are important to cope with global warming; window area and glazing system are beneficial and sensitive to climate change, whereas the shading devices are moderate and insensitive to global warming. Brown et al. [2] found that the best-fitting cooling degree days (CDDs) have a set point of 67°F, for both residential and commercial buildings in the United States, rather than the conventional 65°F. However set points vary by region, with warmer regions tending to have higher set points.

Although the studies of the impact of climate change on the energy consumption of various building types have been conducted in many countries, research on mitigation and alleviation of the impact of climate change on building energy demands is still very limited. The measures of mitigating the climate change impact on buildings should consider locality of building features, climate, building codes, and customs. In Florida, cooling is a major concern in order to maintain the indoor comfort standards and to respond to the energy efficiency requirements from the government [13,14]. According to the reports of U.S. Energy Information Administration, commercial buildings in Florida accounted for about 24% of total energy in 2015 [20]. Research conducted by Jiang et al. [13] indicated the cooling demand will increase in the coming decades at various rates ranging between 26% and 80% in Florida, depending on the commercial building types and locations. It is imperative to investigate the mitigation measures of the climate change impact on the commercial buildings in Florida in order to alleviate the energy demands and maintain indoor comfort standards. Xu et al. [29] pointed out that climate change could change the balance between cooling and heating requirements in the code. The following analysis will provide guidance for needed changes in Florida building energy efficiency codes to address global climate change impacts at the building level. The next section describes the methodology for conducting the research.

2. Methodology

2.1. Current and future weather

Due to its large east-west and north-south geographical span, there are nine climate zones in Florida (Fig. 1) according to Florida Building Code [7]. This study selected eight typical cities from the nine climate zones. The current weather data of the selected cities were obtained from the National Renewable Energy Laboratory (NREL; [25]). Although there are a few mathematical methods to downscale and predict the future weather, such as stochastic weather generation [21,29], and interpolation weather generation [4], "morphing" with global circulation models (GCM) data is adopted for this study due to reliability and consistency of current baseline weather data [13]. By applying the morphing algorithm, future weather data for the 2050s and the 2080s was generated for the selected cities in Florida [13]. Then, the future weather data was converted to energy plus weather (EPW) files for building energy simulation. The weather parameters in EPW files include dry-bulb temperature (°C), relative humidity (%), wind speed (m/s), and solar radiation (W/m^2) which have the main impact on energy demands [15]. By analysing the weather data in EPW files, it was discovered that solar radiation and wind speed would not have appreciable change in the selected cities during the period 2020–2100. However, the dry-bulb temperature of the selected cities would increase all year round. It is anticipated that the temperature would have appreciable increase from the late April through the middle of October in the cities of north Florida, including Pensacola, Tallahassee, and Jacksonville. The maximum increase of the temperature would occur in June, July, and August — as much as about 7 °C. The cities in south Florida, such as Fort Myers and Miami, would have appreciable temperature increases as early as January through the end of December. The maximum temperature increase would be about 5 °C from June through October. In other words, the predictive temperature would rise state wide due to climate change. The north area would have higher temperature increases than the southern areas in June, July, and August, while the southern areas would have longer lasting temperature increases. The relative humidity in the cities of north Florida would be reduced from the late April through the early September in the future, especially in the cities of northwest Florida such as Pensacola and Tallahassee. The maximum reduction would happen in June and July — as much as 10% in Tallahassee. Figs. 2 and 3 show the comparison of current and future (2050 and 2080) dry-bulb temperatures and relative humidity of the eight cities in Florida.

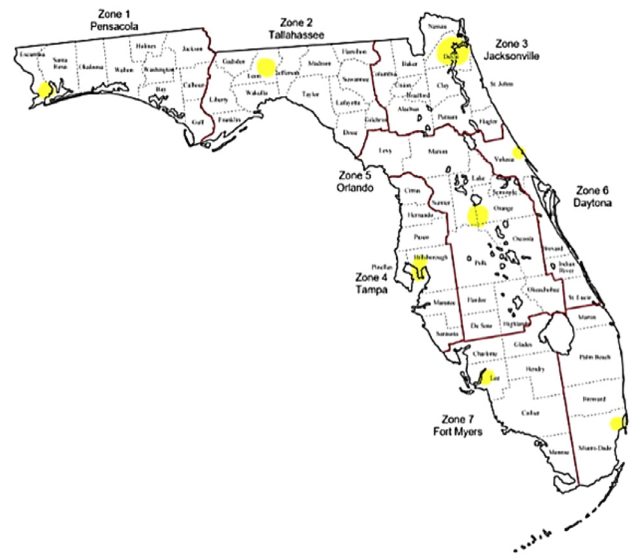

Fig. 1. Climate zones in Florida.

2.2. Measures of mitigating energy consumption

The sub-chapter 4 of Chapter 13 in Florida Building Code stipulates the code compliance in the commercial building systems to

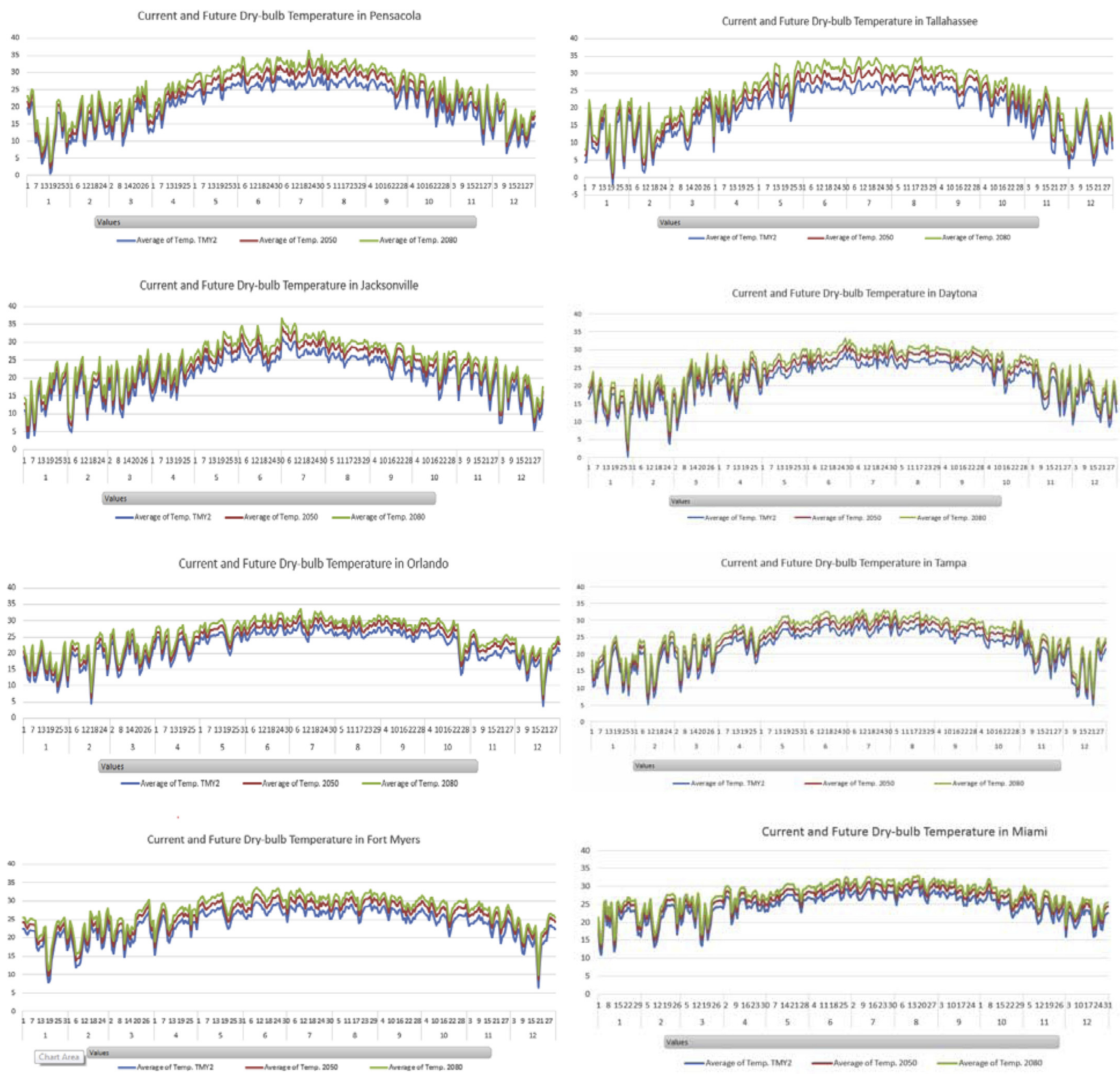

Fig. 2. Comparison of current and future dry-bulb temperature (in °C) in the selected cities.

achieve energy efficiency. It includes fenestrations, walls, roofs and ceilings, floors, air infiltration, space heating and cooling systems, ventilation systems, etc. Table 1 shows the minimum or maximum requirements of main building components which affect the energy consumption, such as insulation of wall, roof, and foundation of commercial buildings. According to the energy efficiency code of commercial buildings in Florida and literature review, the study assessed the mitigation of energy consumption due to the climate change through changing:

- Insulation R-value of wall and roofing systems.
- Window features in terms of glazing material and thermal conductivity.
- Set point temperature/cooling degree days.

The mitigation measures exclude shading to control solar gains since shading is a difficult factor to require through the Florida building code, unlike window types and thermostat set points. In addition, Radhi [17] pointed out that the shading devices are moderate and insensitive to global warming.

Since commercial buildings in Florida consume almost one quarter of total energy of the state, energy consumption of four typical building types in the selected cities are assessed, including high-rise apartment buildings, medium office buildings, secondary schools, and small hotels (Fig. 4). These buildings as reference buildings meet the minimum requirements of Florida building energy efficiency code and are used in the energy consumption simulation. Table 2 describes the main features of each building type, including architecture and HVAC systems.

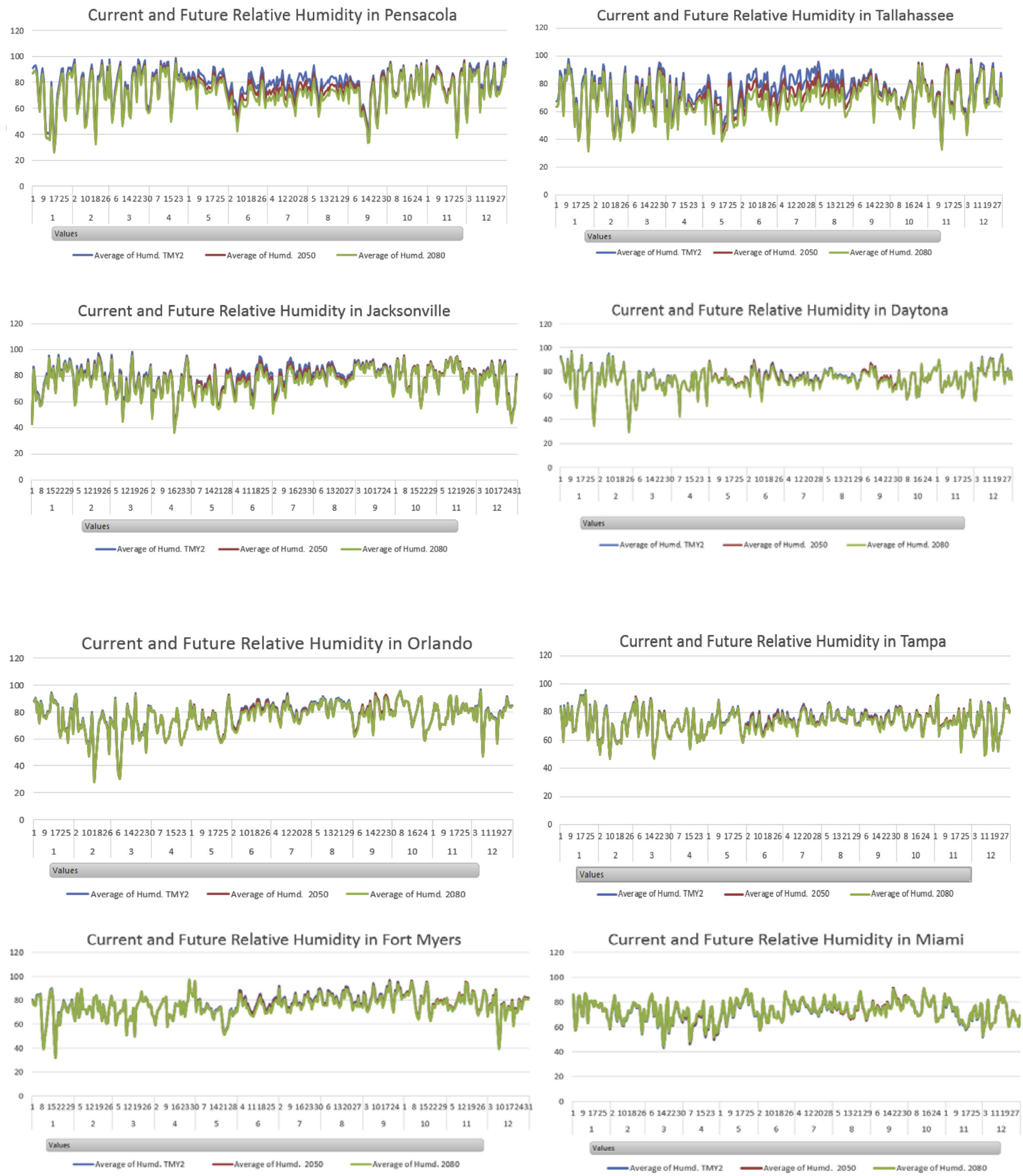

Fig. 3. Comparison of current and future relative humidity (in %) of the selected cities.

Due to the recognition of EnergyPlus (E+) in building energy simulation and acceptance of EPW weather files by E+ [3,13,26], developed by the U.S. Department of Energy Building Technologies Office in building energy consumption research [5], the study applied E+ to simulate the current and future building energy demands with the measures addressed above. Table 3 shows main simulation parameters of each building type. The following section analyzes the results of energy demand simulation of the selected commercial buildings in all eight cities of Florida per addressed mitigation measures.

Table 1
Commercial building code compliance (extracted from Energy Efficiency in Florida Building Code).

Wall type	Minimum insulation R-value
Concrete	R-7 (exterior, adjacent, and common)
Wood frame	R-11 (exterior, adjacent, and common)
Metal frame	R-13 (exterior, adjacent, and common)
Roof Type	**Minimum Insulation R-value**
Built-up roof	Climate zones 1,2, and 3 R-16
	Climate zones 4,5, and 6 R-14
	Climate zones 7,8, and 9 R-12
Insulation in attic or dropped ceiling cavity	All climate zones R-19
Foundation type	**Minimum insulation R-value**
Slab on grade	R-0
Raised wood	R-19
Raised concrete	R-7

Table 2
Main features of the selected commercial building types.

Type	High-rise apartment	Medium office building	Secondary school	Small hotel
Floor area	84,360 SF	53,600 SF	210,900 SF	43,200 SF
# of Floors	10	3	2	4
Floor height	10 ft	13 ft	13 ft	Ground floor: 11 ft Upper floors: 9 ft
Exterior wall	Steel-frame walls (2 × 4 16 in. OC), 0.4 in. Stucco, 5/8 in. gypsum board, wall insulation, 5/8 in. gypsum board	Steel-frame walls (2 × 4 16IN OC) 0.4 in. Stucco + 5/8 in. gypsum board + wall Insulation + 5/8 in.	Steel-framed walls (2 × 4 16″ OC) 0.4″stucco, 5/8″ gypsum board, wall insulation, 5/8″ gypsum board	Steel-frame walls (2 × 4 16in. OC) 1″ stucco, 5/8″ gypsum board, wall insulation, and 5/8″ gypsum board
Roof	Built-up Roof: Roof membrane, roof insulation, and metal decking	Built-up Roof: Roof membrane + Roof insulation + metal decking	Built-up Roof membrane + Roof insulation + Metal decking	Built-up Roof: Roof membrane, roof insulation, and metal decking
Foundation	Slab-on-grade floors (unheated), 6″ concrete slab poured directly on to the earth	Slab-on-grade floors (unheated), 8″ concrete slab poured directly on to the earth	Slab-on-grade floors (unheated), 6″ concrete slab poured directly on to the earth + carpet	Slab-on-grade floors (unheated), 6″ concrete slab poured directly on to the earth
Interior partitions	2 × 4 uninsulated stud wall	2 × 4 uninsulated stud wall	2 × 4 uninsulated stud wall	2 × 4 uninsulated stud wall with 1″ gypsum board
Heating type	Water source heat pumps	Gas furnace inside the packaged air conditioning unit	Gas furnaces inside packaged air conditioning units	ISH (individual space heater), furnace Guest rooms: PTAC with electric resistance heating Public spaces (office, laundry, lobby, and meeting room): gas furnace inside the packaged air conditioning units Storage and stairs: electric cabinet heaters
Cooling type	Water source heat pumps	Packaged air conditioning unit	1. Packaged air conditioner 2. Air-cooled chiller	IRAC (individual room air conditioner), PACU Guest rooms and corridors: PTAC Public space: Split system with DX cooling Storage and stairs: No cooling

3. Results

The cooling and heating demands in TMY2 (TMY3), 2050, and 2080 of the eight cities in Florida have been extracted from the simulation outputs. The outputs show that the heating demands of the selected cities will be reduced. The cities in climate zones 7, 8, and 9 no longer need any heating in the future. Since cooling demands are the main concerns currently and in the future in Florida, the following sections focus on the analysis of cooling consumption of the selected commercial building types.

3.1. Insulation R-value of wall and roof systems

3.1.1. Apartments

The high-rise apartments have built-up roofing and steel-frame wall systems. According to Energy Efficiency in Florida Building Code, the thermal resistance R values of wall systems of this type of building in all climate zones should be at least R-13. The R values of roofing systems vary in different climate zones. Climate zones 1, 2, and 3 require at least R-16; climate zones 4, 5, and 6 require R-14 or above; while the requirements of climate zones 7, 8, and 9 are at least R-12. Fig. 5 shows the current and future cooling demands in unit area (kWh/m^2) of the eight selected cities in which the apartments have various wall and roofing thermal resistances. The standard scenarios indicate that the apartments meet the minimal thermal resistance requirements in wall and roofing systems. Since the dry-bulb temperature and relative humidity are projected to be increased due to the global warming in all climate zones at varied rates and months, the cooling demands will grow at various rates [13]. Therefore, the study simulates cooling demands by changing the thermal resistances in wall or/and roofing systems to R19 and R20 (Fig. 5) to mitigate the energy consumption in the future.

- The standard scenario: The cooling demands of the selected cities are 30–40 kWh/m^2 in climate zones 1, 2, 3, and 6, 40–

Table 3
Main simulation parameters of the selected commercial building types.

Climate zone Cities		1 Pensacola	2 Tallahassee	3 Jacksonville	4 Tampa	5 Orlando	6 Daytona	7 Fort Myers	8 Miami
Window U-value (Btu / h · ft^2 ·°F)		0.87	0.87	0.87	0.48	0.48	0.48	0.48	0.48
Window Solar Heat Gain Coefficient		0.25	0.25	0.25	0.25	0.25	0.25	0.25	0.25
Window Heat Transfer Coefficient		0.9	0.9	0.9	0.9	0.9	0.9	0.9	0.9
Exterior Wall Insulation R-value		13	13	13	13	13	13	13	13
Roof Insulation R-value		16	16	16	14	14	14	12	12
Foundation Insulation R-value		0	0	0	0	0	0	0	0
Air Infiltration of fenestration (cfm/lf)		0.3	0.3	0.3	0.3	0.3	0.3	0.3	0.3
Peak infiltration of exterior wall (cfm/lf)		0.2016	0.2016	0.2016	0.2016	0.2016	0.2016	0.2016	0.2016
Cooling set point	High-rise apartment	75 °F							
	Medium office	75 °F							
	Secondary school	75 °F							
	Small hotel	70 °F for occupied guest rooms 74 °F for vacant guest rooms 75 °F for public spaces (lobby, meeting room etc.)							
Heating set point	High-rise apartment	70 °F							
	Medium office	70 °F							
	Secondary school	70 °F							
	Small hotel	70 °F for occupied guest rooms 66 °F for vacant guest rooms 70 °F for air conditioned public spaces (lobby, meeting room etc.) 45 °F heating for stairs and storage rooms							
Cooling setback point	High-rise apartment	None							
	Medium office	80 °F							
	Secondary school	85 °F							
	Small hotel	74 °F							
Heating setback point	High-rise apartment	None							
	Medium office	60 °F							
	Secondary school	60 °F							
	Small hotel	66 °F							

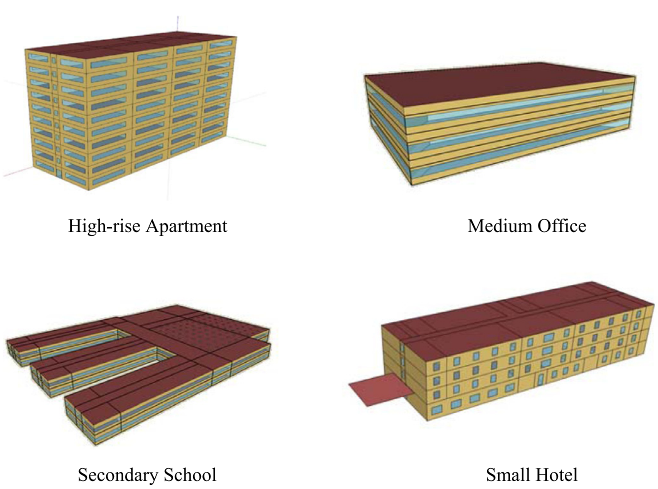

Fig. 4. Four typical commercial building types.

50 kWh/m^2 in zones 4 and 5, and 50–60 kWh/ m^2 in zones 7 and 8. They are projected to increase to 50–60 kWh/m^2 in the cities of climate zones 1, 2, 3, and 6 in 2080 which will be below the average state cooling demands 64 kWh/m^2 in 2080. Cooling demands will increase to 60–70 kWh/ m^2 in the cities of climate zones 4 and 5, which are approximately the same as the average state cooling demands in 2080. Miami (zone 8) and Fort Myers (zone 7) will increase in cooling energy consumption to 70–80 kWh/m^2 which is above the average state cooling demands in 2080.

- Roof thermal resistance R-19 and R-20 scenario: Increasing the roofing thermal resistance to R-19 and R-20 to reduce the energy consumption. The cooling demands of the selected cities are reduced in this scenario compared to the ones in the standard scenario. However, the reduction rates are within 3–4% currently and in future decades.
- Wall thermal resistance R-19 and R-20 scenario: Increasing the wall thermal resistance to R-19 and R-20 to reduce the energy consumption. The cooling demands of the selected cities are reduced in this scenario compared to the ones in the standard scenario. However, the reduction rates are within 3–4.5% currently and in future decades.
- Both roof and wall thermal resistance R-19 and R-20 scenarios: Increasing both roof and wall thermal resistance to R-19 and R-20 to reduce the energy consumption appreciably. The simulation results show that the cooling demands in all selected cities are reduced at various rates between 3.5% and 5% currently and in 2050 and 2080.

3.1.2. Hotels

The small hotels also have built-up roofing and steel-frame wall systems. Therefore, the thermal resistance R values of wall systems in all climate zones are required to be at least R-13. The R values of roofing systems vary in different climate zones as described in the apartment buildings. Fig. 6 shows the current and future cooling demands in unit area (kWh/m^2) of the eight selected cities in which the small hotels have various wall and roofing thermal resistances. The simulation results indicate:

- The standard scenario: The cooling demands of the selected cities are 40–50 kWh/m^2 in climate zones 1, 2, and 3; 50–60 kWh/m^2 in zones 4, 5, and 6; and 60–70 kWh/ m^2 in zones 7 and 8. They are projected to increase to 70–80 kWh/m^2 in the cities of climate zones 1, 2, and 3 in 2080 which would be below the average state cooling demands 78 kWh/m^2 in 2080. Cooling demands will increase to 77 kWh/m^2 (close to the average 78 kWh/m^2 in 2080) in the cities of climate zones 4, 5 and 6. The cities in climate zones 7 and 8 will increase the cooling energy consumption to about 90 kWh/m^2 which would be above the average state cooling demands 78 kWh/m^2 in 2080.

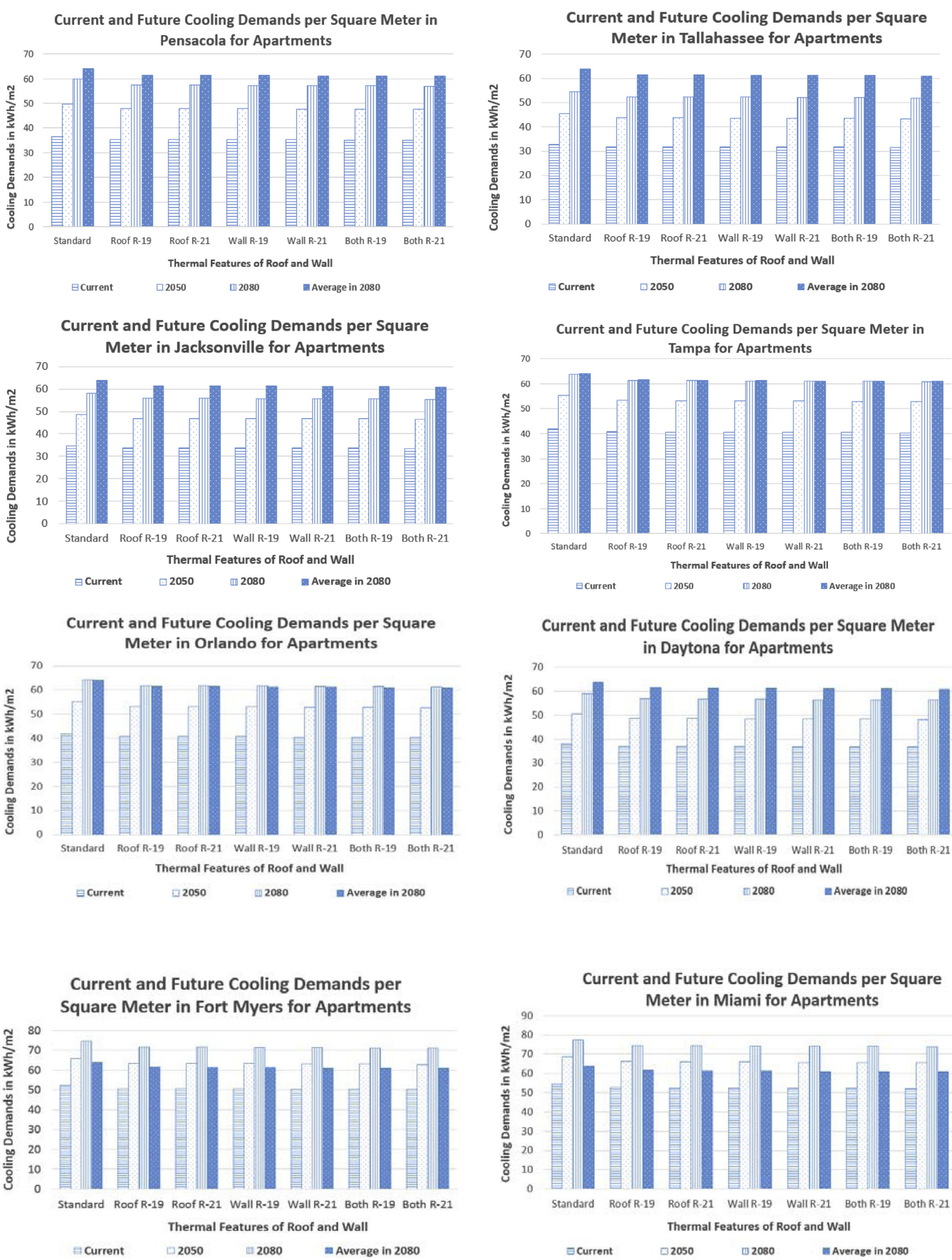

Fig. 5. Cooling demands of apartments in the selected cities.

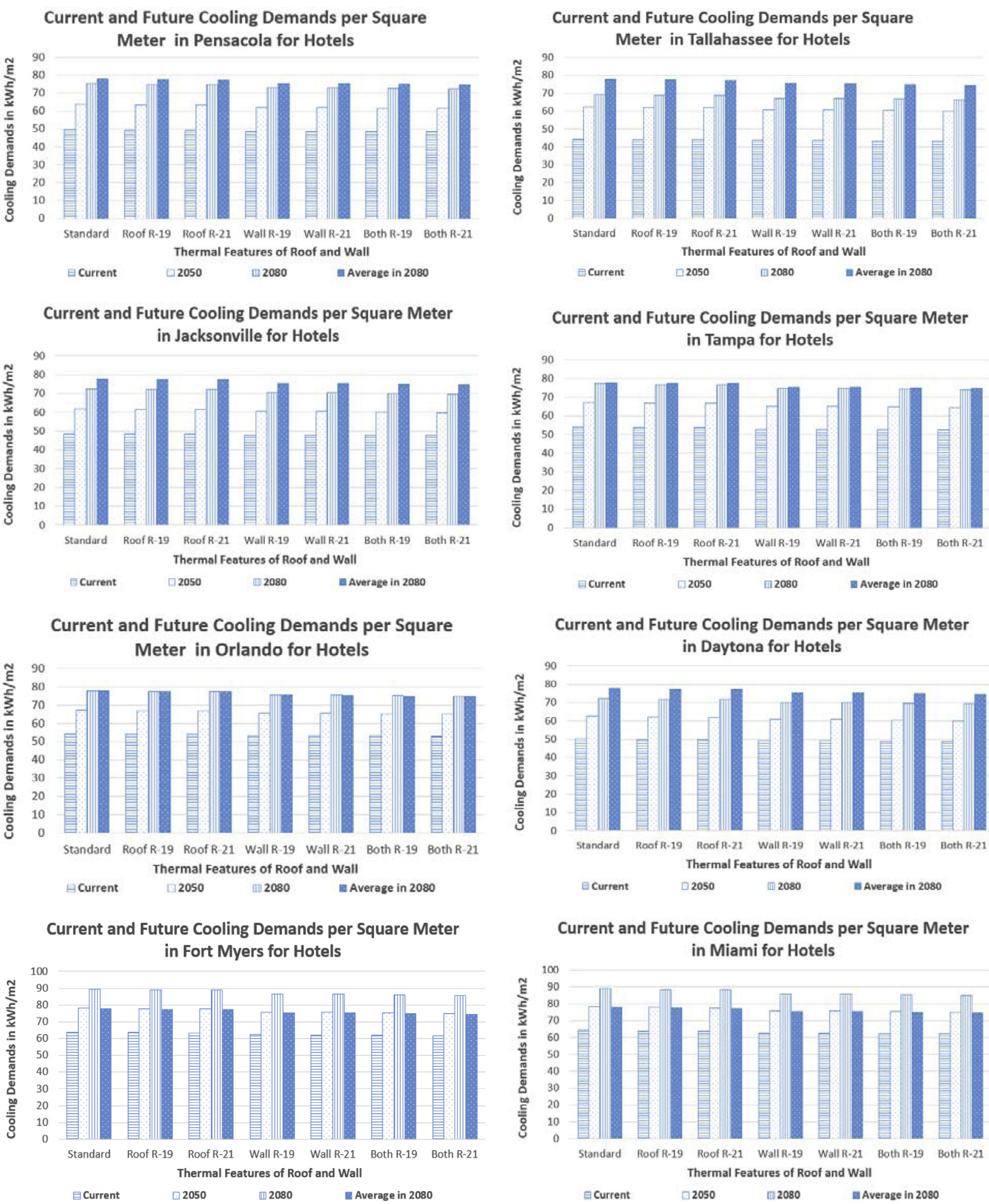

Fig. 6. Cooling demands of hotels in the selected cities.

- Roof thermal resistance R-19 and R-20 scenario: The cooling demands of the selected cities are reduced in this scenario compared to the ones in the standard scenario. However, the reduction rates are within 1% currently and in the future.
- Wall thermal resistance R-19 and R-20 scenario: The cooling demands of the selected cities are reduced in this scenario compared to the ones in the standard scenario. The reduction rates are between 1.5 and 3.5% currently and in the future.
- Both roof and wall thermal resistance R-19 and R-20 scenarios: The simulation results show that the cooling demands in all selected cities are reduced at various rates compared to the ones in the standard scenario. The reduction rates are among 1.8–4.5% currently and in the future.

3.1.3. Office buildings

The built-up roofing and metal wall systems of the referenced medium office buildings have the same minimal thermal resistance requirements as the above studied buildings according to Energy Efficiency in Florida Building Code. The simulation results of this type of buildings (Fig. 7) show:

- The standard scenario: The cooling demands of the selected cities are 40–50 kWh/m^2 in climate zones 1, 2, 3, and 6; about 50 kWh/m^2 in zones 4 and 5; and around 60 kWh/m^2 in zones 7 and 8. They are projected to increase to 70–80 kWh/m^2 in the cities of climate zones 1, 2, 3, and 6 in 2080 which would be below the average state cooling demand of 80 kWh/m^2 in 2080. Cooling demands will increase to 80 kWh/ m^2 in the cities of climate zones 4 and 5, which are approximately the same as the average state cooling demands 80 kWh/m^2 in 2080. Miami (zone 8) and Fort Myers (zone 7) will increase cooling energy consumption to 90 kWh/m^2 which would be above the average state cooling demand in 2080.
- Roof thermal resistance R-19 and R-20 scenarios: The cooling demands of the selected cities are reduced in these scenarios compared to the ones in the standard scenario. However, the reduction rates of the selected cities are within 1% currently and in the future.
- Wall thermal resistance R-19 and R-20 scenarios: The cooling demands of the selected cities are reduced in these scenarios. The reduction rates of the selected cities are between 2–3% currently and in the future compared to the standard scenario.
- Both roof and wall thermal resistance R-19 and R-20 scenarios: The cooling demand reduction rates of office buildings in all climate zones are between 2.5–3.5% currently and in the future.

3.1.4. Schools

The built-up roofing and metal wall systems of the referenced secondary school buildings have the same minimal thermal resistance requirements as the above-studied buildings according to Energy Efficiency in Florida Building Code. Fig. 8 shows the simulation results of the secondary schools with various thermal resistance features of wall and roofing systems in different time periods:

- The standard scenario: The cooling demands of the selected cities are 75–85 kWh/m^2 in climate zones 1, 2, 3, and 6; about 90 kWh/m^2 in zones 4 and 5; and around 110 kWh/m^2 in zones 7 and 8. They are projected to increase to 125–140 kWh/m^2 in the cities of climate zones 1, 2, 3, 4, 5 and 6 in 2080 which would be below the average state cooling demand of 143 kWh/m^2 in 2080. Miami (zone 8) and Fort Myers (zone 7) will increase the cooling energy consumption to about 165 kWh/m^2 which would be above the average state cooling demand in 2080.
- Roof thermal resistance R-19 and R-20 scenarios: The cooling demand reduction rates of the selected cities are within 1–2% currently and in the future.
- Wall thermal resistance R-19 and R-20 scenarios: The cooling demand reduction rates of the selected cities are also within 1–2% currently and in the future compared to the standard scenario.
- Both roof and wall thermal resistance R-19 and R-20 scenarios: The simulation results show that the cooling demands in all selected cities are reduced at various rates. The reduction rates are between 1.5–3.5% currently and in the future.

Among the studied commercial building types, the secondary schools have highest cooling demands per unit area (kWh/m^2) while the apartments have lowest cooling demands, since the secondary schools hold more persons, active indoor activities, larger kitchen equipment, and cafeterias. The buildings located in climate zones 7 and 8 usually have highest cooling demands while the ones located in climate zones 1, 2, 3, and 6 have the lowest demands. The reason is apparently the higher temperatures and relative humidity in the climate zones 7 and 8. The cooling demands are reduced at various rates in all studied building types and in all climate zones by changing the thermal resistances of roofing systems and wall systems. The apartment buildings benefit more than other building types in terms of reducing the cooling demands, since apartment buildings have higher window fraction and building aspect ratio (total floor area vs. building exterior envelope). Compared to increasing the thermal resistance of roofing systems, the cooling demands are reduced more by increasing the thermal resistances of wall systems in all studied building types. It is probably that the areas of exterior walls of the building types are larger than the areas of roofs. Although the cooling demands are reduced most by changing the thermal resistance of both roofing and wall systems, the advantage is not appreciable compared to increasing the R values of wall systems only, especially in apartment and office buildings.

3.2. Window features

Window features include glazing material's visible transmittance (VT) and solar transmittance (ST) at normal incidence and thermal conductivity of windows. VT and ST are the amounts of visible light and light respectively that pass through a glazing material. Higher VT and ST mean more daylight, accordingly warmer, in a space. The ranges of VT and ST fall between 0 and 1. The value ranges of VT and ST of selected building simulation models are 0.08–0.0898 and 0.06–0.831 respectively according to functionalities of rooms has. A thermal conductivity of a window is measured in K-value or W/m·K. It measures how quickly heat passes through window. The lower the value, the better insulation the window is. The thermal conductivity of windows in the referenced buildings is 0.9 (refer to Table 3). Based on the Efficient Windows Collaboratives [6] study, this study simulates the current and future cooling energy consumption by changing the values of VT and ST to 0.3 and 0.2 respectively (see Table 4) and changing the values of thermal conductivity from 0.9 to 0.3 (see Table 4) to achieve energy efficient window requirements. Through this time-consuming simulation and output data analysis, it is found that there is no significant decrease in current and future cooling demands in all selected types of buildings except high-rise apartments by changing the VT and ST of glazing materials. Both the current and future cooling demand decreases in a percentage between 2% and 3.5% as for high-rise apartments between standard model and the changed model, while the models of other types of buildings are near 0%. Cities in the southern areas have more significant cooling demand rate decrease than the cities in the central and northern areas. In

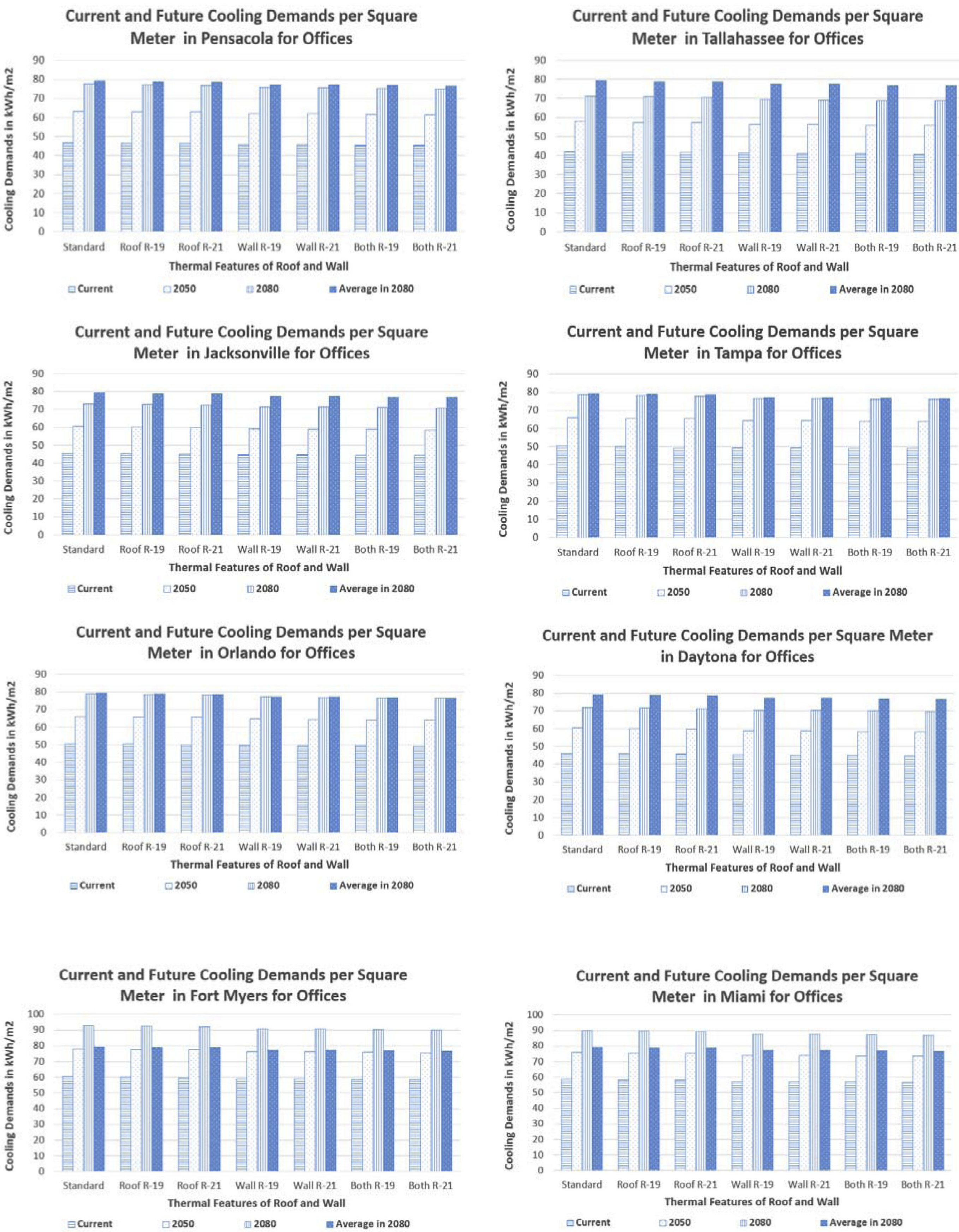

Fig. 7. Cooling demands of offices in the selected cities.

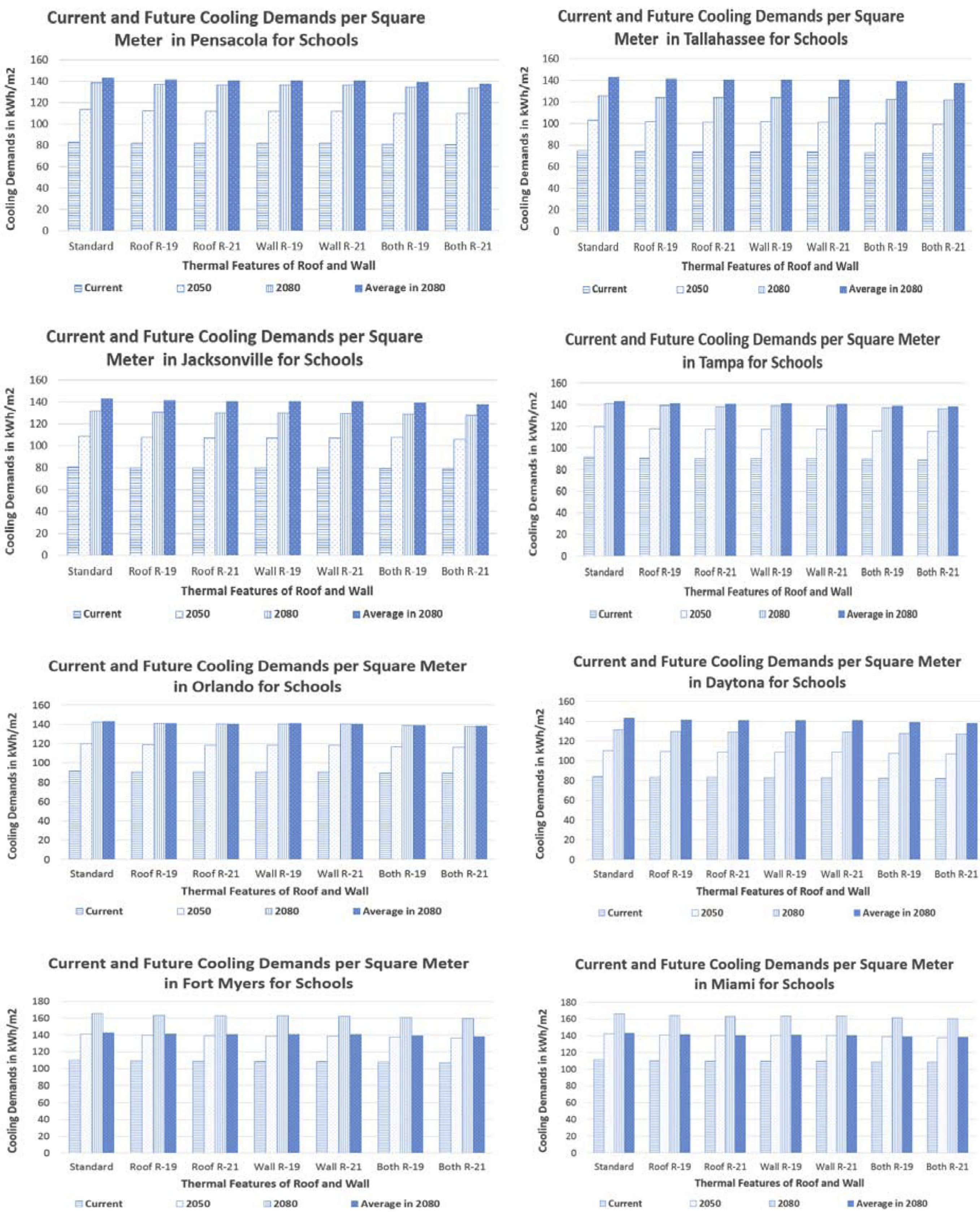

Fig. 8. Cooling demands of schools in the selected cities.

Table 4
Current and future cooling demands and changes of high rise apartment in Miami by changing VT, ST, and thermal conductivity of window.

Visible transmittance (VT) at normal incidence					
Time	Standard VT (Range)	Standard cooling end use (kWh)	Changed VT	Changed cooling end use (kWh)	Change of consumption (in %)
Current	0.08–0.898	383,650.13	0.3	373,188.19	−2.73
2050	0.08–0.898	485,199.92	0.3	468,934.73	−3.35
2080	0.08–0.898	546,990.98	0.3	527,861.67	−3.50
Solar Transmittance (ST) at Normal Incidence					
Time	Standard ST (Range)	Standard cooling end use (kWh)	Changed ST	Changed cooling end use (kWh)	Change of consumption (in %)
Current	0.06–0.831	383,650.13	0.2	373,188.19	−2.73
2050	0.06–0.831	485,199.92	0.2	468,934.73	−3.35
2080	0.06–0.831	546,990.98	0.2	527,861.67	−3.50
Thermal conductivity (W/mK or K-Value)					
Time	Standard conductivity (Range)	Standard cooling end use (kWh)	Changed conductivity	Changed cooling end use (kWh)	Change of consumption (in %)
Current	0.9	383,650.13	0.3	376,107.86	−1.97
2050	0.9	485,199.92	0.3	469,993.15	−3.13
2080	0.9	546,990.98	0.3	528,133.91	−3.45

addition, the current and future decreases of cooling demand are more noticeable (decrease rate is up to 3.5%) in high-rise apartments than other types of buildings, especially in southern areas of Florida, by changing the K-value 0.9 to 0.3 to increase window insulation. Table 4 shows the current and future cooling demands of high-rise apartments in a typical city of Florida, Miami, by changing the VT and ST of glazing materials and thermal conductivity of window. Since the future weather is anticipated to be hotter and dryer in Florida for longer periods in one year, more cooling energy consumption would be saved by changing the VT, ST and thermal conductivity of windows to energy efficient values in high-rise apartments.

3.3. Set point temperature/cooling degree days

Changing set point temperatures or decreasing cooling degree days by raising cooling set points is another measure addressed in literature to mitigate cooling demands. Wan et al. [21] and Brown et al. [2] suggested to set the cooling set point as 78 °F (25.5 °C) in Hong Kong and 67 °F (19.4 °C) in the United States respectively. Table 3 shows the standards for the cooling set point temperatures, which are extracted from building simulation models, of all selected types of referenced buildings across Florida. The cooling set point of high-rise apartments is 75 °F (23.9 °C). The median office has an average thermostat set point of 74.41°F (23.6 °C), while the highest allowable set point is 75 °F (23.9 °C). The average cooling set point of the secondary school building simulation model also has a set point of 75 °F (23.9 °C). Hotel buildings have different cooling set points per the functionalities of rooms and spaces. According to Brown et al. [2], all of the cooling set points of the simulated building types are above his currently suggested set point in the United States — 67 °F (19.4 °C). In addition, the standards of thermostat set points used by simulation models are not suggested to be higher due to OSHA standards. Therefore, this study suggests a 75 °F (23.9 °C) cooling set point.

4. Conclusion

Global climate change has raised public awareness of energy use and the environmental implications and generated a lot of interest in having a better understanding of the energy use characteristics in buildings [13]. This study shows that the north Florida area would have a higher temperature increase than the southern areas in June, July, and August while the southern areas would have a longer lasting temperature increase. Meanwhile, the northwest Florida area will be drier from late April through early September. A particularly consequential impact on building cooling electricity usage is anticipated in Florida. Although many studies have found that global warming would cause a decrease in heating requirements and an increase in cooling requirements, few of the studies propose mitigation of the cooling demands of the buildings. In addition, the measures of mitigating the climate change impact on buildings should consider locality of building features, climate, building codes, and customs. The commercial buildings in Florida accounted for about 24% of the total energy in Florida in 2015. Therefore, the research on the mitigation of cooling demands in commercial buildings is significant in both maintaining the indoor comfort standards and meeting the energy efficiency requirements of the governing bodies. This study investigates the current and future cooling demands of four main commercial buildings in eight selected cities of nine climate zones of Florida by accommodating the thermal resistance features of wall and roofing systems, features of windows in terms of visible and solar transmittance, and set point temperature/cooling degree days. This study shows that:

- Among the studied commercial building types, the secondary schools have the highest cooling demands per unit area 75–110 kWh/m^2 while the apartments have lowest cooling demands 30–60 kWh/m^2.
- The buildings located in southern Florida usually have the highest cooling demands, while the buildings located in northern and central eastern Florida have the lowest demands regardless of the building types.
- The cooling demands are reduced at various rates in all studied building types and in all climate zones by changing the thermal resistance of roofing systems from R-12/14/16 to R-19/21 and wall systems from R-13 to R-19/21. The cooling demands of apartment buildings can be reduced as much as 5% by changing the wall and roofing thermal resistance to R-21. The cooling demands of secondary schools are least sensitive to the change in thermal resistance; the reduction rate is as much as 3.5%.
- Since the buildings have more exterior wall area than roof areas of the buildings, the cooling demands are reduced more by increasing the thermal resistance of wall systems in all studied building types.
- Although the cooling demands are reduced most by changing the thermal resistances of both roofing and wall systems, the advantage is not appreciable compared to increasing the R values of wall systems only. In other words, increasing the wall thermal resistance features is more efficient in mitigating the

cooling demands of buildings than accommodating the thermal resistance features of roofing systems.

- The current and future cooling demands are anticipated to be decreased noticeably in high-rise apartments by changing VT to 0.3, ST to 0.2, and thermal conductivity to 0.3, due to its high aspect ratio (areas of window to exterior wall), especially in south Florida. The decreased cooling demands in percentage are between 2% and 3.5%.
- The average cooling set point temperature of all simulated buildings is 75 °F (23.9 °C) which is far above the suggested temperature of 67 °F (19.4 °C). Due to OSHA standards, it is not suggested that the cooling set point exceed 75 °F (23.9 °C).

Per our findings in this study, it is suggested that buildings with a high aspect ratio may mitigate cooling demands by increasing visible and solar transmittance of glazing materials and thermal conductivity of windows, such as high-rise apartments. In Florida, the average values of VT and ST of glazing materials and thermal conductivity of windows for a high-rise apartment are suggested to be 0.3, 0.2, and 0.3 respectively. As for buildings, which have more exterior wall areas than roof areas, it is suggested that increasing the thermal resistance features of wall systems is a more efficient measure to mitigate energy consumption in Florida than increasing the thermal resistance features of roofing systems. Although increasing the wall thermal resistance features is an efficient way to mitigate the cooling demands of buildings, the construction cost of replacing the lower R-value materials of wall systems with higher R-value (like R-19 or R-21) materials has to be considered. If the savings in cooling consumption is more than the additional construction cost, it is worthwhile to revise the thermal resistance code of commercial building wall systems. This research studies mitigating the cooling demands of buildings in Florida. Further studies will be conducted which pertain to typical commercial and residential buildings in other areas of the United States and world wide by applying the proposed mitigating methods.

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